PRODUCTION OF F-18 AND TC-99M RADIONUCLIDES USING AN 11-MEV PROTON-ACCELERATING CYCLOTRON*

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Abstract

An 11-MeV proton-accelerating cyclotron has been employed to produce F-18 and Tc-99m radionuclides. In this report, F-18 radionuclide was produced from enriched-water ($H_2{}^{18}O$) target whereas Tc-99m was generated from natural molybdenum trioxide (MoO_3) target. Two recoiled radioactive impurities such as Co-56 and Ag-110m are identified in the F-18 solution whereas N-13 was recognized as an impurity in the Tc-99m production. The Co-56 radionuclidic impurity is presumably sputtered off the havar window in the target system whereas Ag-110m is originally from a silver body housing the enriched water target which is generated by secondary neutron irradiated Ag-109. In addition, N-13 impurity found in the post-irradiated MoO_3 target occurs presumably via (p,α) nuclear reaction.

INTRODUCTION

Positron and gamma ray emitting radionuclides such as F-18 and Tc-99m have been used for medical imaging of tumors, cancers and other metabolism-related diseases via the-so-called Positron Emission Tomography (PET) and Single Photon Emission Computed Tomography (SPECT) [1-4]. In Indonesia, F-18 radionuclide has been routinely produced using an 11-MeV cyclotron at Dharmais Cancer Hospital [5], whereas cyclotron-produced Tc-99m is still under investigation. Previous research suggested that radionuclidic impurities such as Co-56 and Ag-110m radionuclides were identified in the post-irradiated enriched water target, though it did not quantify the radioactivities. Further studies are, therefore, required to better understand the amount of impurities and their dependence on the proton beam doses.

In terms of technetium-99m, it has been reported that the most widely used radionuclide in nuclear medicine has experienced shortages lately [6-7] since production of the gamma emitting radioisotope has been mostly carried out using nuclear reactors while the rate of new nuclear reactor establishments is slowing down and the number of aging reactors is increasing. An alternative method of producing Tc-99m using cyclotrons has been proposed elsewhere [8] to tackle the shortage issues. Medium energy protons in the range of 8 – 18 MeV have been suggested to irradiate molybdenum (Mo) targets [9], either natural or enriched Mo to obtain high specific activity of Tc-99m, though enriched Mo-100 is preferred for better yields [10].

In this paper, production of F-18 radionuclide at different integrated proton beam currents or doses is discussed and dependence of impurity intensities on proton beam current is also presented. Moreover, preliminary result of Tc-99m production using an 11-MeV cyclotron is also highlighted in this report.

EXPERIMENTAL METHOD

The 11 MeV Cyclotron

The cyclotron employed in this investigation is a typical Eclipse Radioisotope Delivery System (RDS) 111 cyclotron located at the National Cancer Center (NCC), Dharmais Cancer Hospital in Jakarta, Indonesia, which has been described elsewhere [5]. The cyclotron accelerates 11-MeV protons at a beam current of up to 60 μA, though in this investigation the maximum proton beam employed in the target irradiation is between 20 and 30 μA, depending on the targets of interest, while the irradiation time varied between 15 and 60 minutes.

The Target Systems

The target vessel/body for F-18 production comprises of a silver body/tube and is separated from the beam window by another 50 μm thick Havar foil, which has been described elsewhere [5]. During proton bombardment, havar foil is expected to be activated via (p,n) nuclear reaction, thus the proton-generated radionuclides could potentially contaminate the enriched water target should they recoil off the havar window.

In Tc-99m production, the target system consists of an aluminum tube housing a target holder where the target is placed in, as can be seen in Figure 1. During the target irradiation, the target system was cooled by Helium and water coolant to avoid excessive heat while the temperature was monitored throughout the irradiation procedure.

Production and Analysis of F-18

Fixed energy proton beams of 11 MeV was bombarded into 1.8 mL enriched-water target ($H_2{}^{18}O$). The experiment was conducted at variable proton beam currents between 10 and 30 μA.hr. At the end of the bombardment, F-18 yields and radionuclide impurities were analyzed shortly following an hour cooling period using a portable gamma ray spectrometer. The spectrometer consists of a NaI(Tl) detector coupled to a portable pocket Multi Channel Analyzer (MCA).

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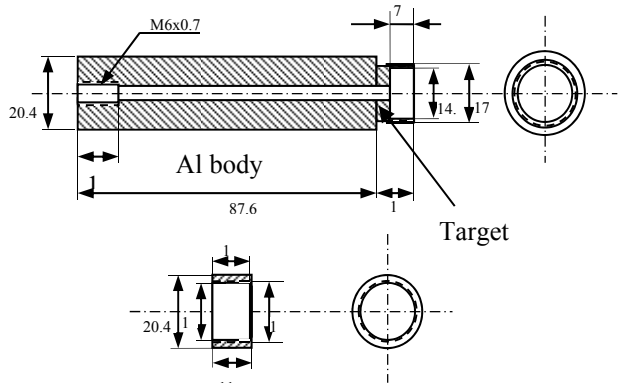

Figure 1: Target system for Tc-99m production at the National Cancer Center, Dharmais Cancer Hospital, Jakarta.

Production and Analysis of Tc-99m

Natural molybdenum trioxide (MoO_3) in the form of pellet was irradiated with the 11-MeV proton beam at an integrated beam current of 5 μA.hr. Following an hour cooling period, the post-irradiated MoO_3 target was dissolved in a NaOH 6M solution and then being analyzed using the portable gamma ray spectrometer. Observations were conducted periodically to understand the evolution of produced Tc-99m as well as impurities found in the post-irradiated target.

RESULTS AND DISCUSSION

Spectrum of F-18 and Target System

Fluorine-18 radionuclide is produced following irradiation of enriched-water ($H_2{}^{18}O$) target, which can be identified from the strong annihilation peak at 0.511 MeV as can be seen in Figure 2.

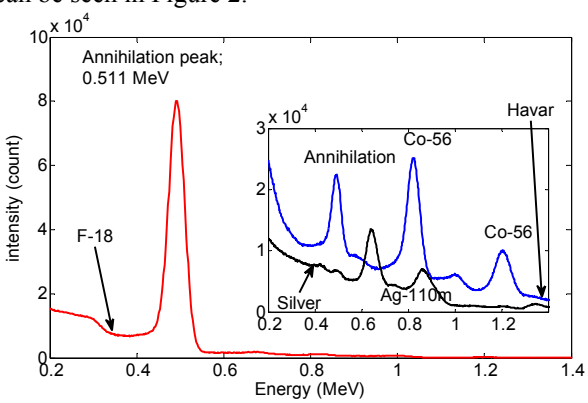

Figure 2: Gamma ray spectrum of F-18 and the target system (Havar foil and silver body).

In the target system, Havar foil which separates the proton beam and $H_2{}^{18}O$ target is also activated by the incoming proton beam resulting in Co-56 radionuclide generated from $^{56}Fe(p,n)^{56}Co$ nuclear reaction, whereas secondary neutrons are expected to cause nuclear reaction when they hit the silver body as discussed elsewhere [5]. As a result Ag-110m radionuclide is generated via $^{109}Ag(n,\gamma)^{110m}Ag$ nuclear reaction. Both Co-56 and Ag-110m are experimentally observed at significant levels as shown in Figure 2 (inset). Evidence suggests that Co-56 observed in the post-irradiated water target is originally from the Havar foil. The Co-56 impurity is presumably recoiled off the Havar window and then fall into the water target. Similarly, Ag-110m is most likely as a result of recoiling/sputtering process.

A total of nearly 588 mCi of F-18 radionuclide is produced at the end of bombardment when 30 μA.hr proton beam dose is directed to the enriched water target, whereas the yield drops to at lower proton beam of 10 μA.hr.

Radionuclidic Impurities

Previous experiment suggested that radionuclidic impurities such as Co-56 and Ag-110m were recorded in the post-irradiated $H_2{}^{18}O$ target [5], and in this investigation their presence is, again, confirmed as can be seen in Figure 4. The strong annihilation peak at 0.511 MeV is presumably as a result of over 1.022-MeV gamma ray interaction with the detector material.

In order to study the dependence of the proton beam dose on the number of Co-56 and Ag-110m impurities, $H_2{}^{18}O$ target was irradiated with proton beam doses between 10 and 30 μA.hr. It is clear from Figure 3 that the amount of the impurities is directly proportional to the proton beam dose.

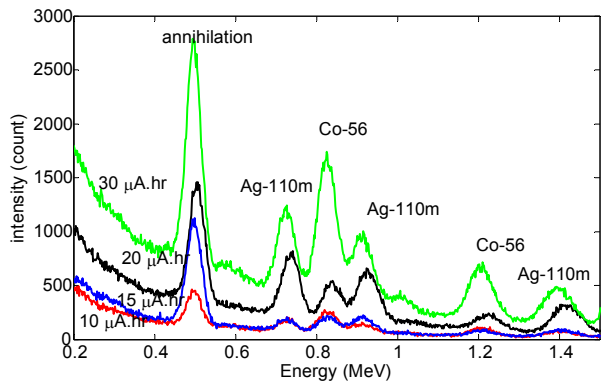

Figure 3: Gamma ray spectrum of radionuclidic impurities observed in F-18 production at variable proton beam intensities ranging from 10 to 30 μA.hr.

Details of the recorded radionuclidic impurities at different proton beam dose are given in Table 1, which indicates that no other impurities than Co-56 and Ag-110m are found in the post-irradiated enriched water target. The measured radioactivity of Co-56 impurities ranges from 0.077 μCi at proton dose of 10 μA.hr to 0.670 μCi at proton dose of 30 μA.hr, whereas Ag-110m exhibits lower radioactivity as shown in Table 1.

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Table 1: Radionuclidic Impurities Observed during F-18 Production

Proton dose (μA.hr)	γ Energy (MeV)	Identified Radionuclide	Activity (μCi)
10	0.511, 0.847, 1.238	Co-56	0.077
	0.511,0.658, 0.885, 1.384	Ag-110m	0.083
15	0.511, 0.847, 1.238	Co-56	0.110
	0.511,0.658, 0.885, 1.384	Ag-110m	0.083
20	0.511, 0.847, 1.238	Co-56	0.202
	0.511,0.658, 0.885, 1.384	Ag-110m	0.330
30	0.511, 0.847, 1.238	Co-56	0.670
	0.511,0.658, 0.885, 1.384	Ag-110m	0.508

Spectrum of Tc-99m

Spectrum of post-irradiated MoO_3 following 30 minutes is given in Figure 4, which exhibits a very strong peak at 0.511 MeV belonging to N-13 radionuclide produced via $^{16}O(p,\alpha)^{13}N$ nuclear reaction, though the N-13 intensity completely disappears following a 24-hours cooling period (Note that N-13 half life is nearly 10 minutes. Apart from the N-13 peak, other peaks are also recorded by the portable spectroscopy system, which correspond to Tc-99m peak at 0.142 MeV, Mo-99 peak at 0.748 MeV, and Tc-96 peak at 0.848 MeV. Production of Tc-99m in this investigation is mostly due to $^{100}Mo(p,2n)^{99m}Tc$ nuclear reaction as well as the decay of Mo-99 which is generated from $^{98}Mo(p,\gamma)^{99}Mo$ nuclear reaction. In addition, the observed Tc-96 impurity is presumably resulted from $^{96}Mo(p,n)^{96}Tc$ nuclear reaction.

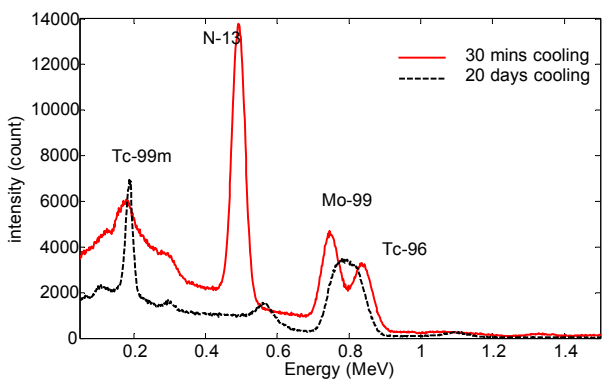

Figure 4: Gamma ray spectrum of post-irradiated MoO_3 following 30 minutes and 20 days cooling respectively.

Following 20 days of cooling period, strong Tc-99m peak dominates while the intensity of Tc-96 impurity is no longer significant (see Figure 4). At the end of bombardment, nearly 13.4 μCi of Tc-99m is produced in this investigation for proton dose of 5 μA.hr. Radionuclides produced from an 11-MeV proton irradiated natural MoO_3 target is listed in Table 2.

Table 2: Radionuclides Produced from Proton-irradiated Natural MoO_3 Target

Radio-nuclide	γ Energy (MeV)	Half-life	Nuclear Reaction
Tc-99m	0.142	6 h	$^{100}Mo(p,2n)^{99m}Tc$
N-13	0.511	10 min	$^{16}O(p,\alpha)^{13}N$
Mo-99	0.748	66 h	$^{98}Mo(p,\gamma)^{99}Mo$
Tc-96	0.848	4.3 d	$^{96}Mo(p,n)^{96}Tc$

CONCLUSION

Using an 11-MeV proton accelerating cyclotron, F-18 and Tc-99m radionuclides have been produced from enriched-water ($H_2{}^{18}O$) target and natural MoO_3 target respectively. In F-18 production, radionuclidic impurities such as Co-56 and Ag-110m are apparent. While Co-56 is presumably generated from $^{56}Fe(p,n)^{56}Co$ nuclear reaction, Ag-110m is most likely due to $^{109}Ag(n,\gamma)^{110m}Ag$ nuclear reaction. Both Co-56 and Ag-110m are expected to recoil off the havar window and silver body respectively and then fall into the enriched-water target. Experimental results also indicate that the impurity intensities increase with increasing proton beam dose.

In Tc-99m production, following an hour of cooling period, N-13 radionuclide is found to dominate the impurities present in the post-irradiated natural MoO_3, which is presumably produced via $^{16}O(p,\alpha)^{13}N$ nuclear reaction. Apart from Tc-99m peak, Mo-99 energy spectrum is also observed in the Tc-99m production route. To get higher Tc-99m yield and less impurities, enriched molybdenum (Mo-100) target is suggested for future investigation.

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